Habitat Changes, Growth and Abundance of Juvenile Giant Spiny Crayfish, *Euastacus hystricosus* (Decapoda: Parastacidae), in the Conondale Ranges, South-east Queensland

GEOFFREY CLIFFORD SMITH[1], ADRIAN BORSBOOM[1], RINA LLOYD[2],
NADYA LEES[1] AND JOHN KEHL[3]
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[1]Resource Sciences Centre, Department of Natural Resources (DNR), P.O. Box 631,
Indooroopilly, Q. 4068; [2]Department of Environment, Brisbane, Q. 4000 and
[3]Forest Allocation and Use, DNR, Mineral House, Brisbane, Q. 4000

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As part of broader investigations of the impacts of catchment activities on water quality and stream faunas, aspects of habitat, growth and abundance of the giant spiny cray, *Euastacus hystricosus*, have been studied (1984–1994) in two creek catchments in the Conondale Ranges.

E. hystricosus juveniles grew during their first summer and autumn; most ceased growing in winter, then resumed growth as water temperature rose again in spring. Slope coefficients of linear regression lines fitted to the growth data for the first growth period to May did not differ significantly between catchments or years. Juveniles were generally larger in Bundaroo Creek in any month, with significant differences in May of 1987 and in 1994. Individuals were also significantly larger in Bundaroo Creek in October of 1993 and 1994.

While population fluctuations within each stream were similar, densities of crayfish along the Bundaroo Creek survey transect were slightly lower than the transect on North Booloumba Creek. Turbidity was usually higher in North Booloumba Creek which may, in part, explain differences in growth rate; however, uneven precipitation in the Conondale area and short-term effects of rain events on stream turbidity would contribute to poor correlation of rainfall records with growth or abundance.

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KEYWORDS: Juveniles, growth, population size, *Euastacus hystricosus*, paired catchment, habitat, environmental conditions.

INTRODUCTION

The Giant Spiny Crayfish *Euastacus hystricosus* (Morgan 1988; Riek 1951) is restricted to upland streams surrounded by rainforest or wet sclerophyll forest in the Conondale and Blackall Ranges of south-eastern Queensland (Morgan 1991). Females mate and spawn in autumn (March to April) and incubate eggs, attached to their pleiopods, from May to September (Kehl, unpublished data; Turvey and Merrick 1997a). However there is little published information on other aspects of the biology or ecology of this species.

This situation reflects a general lack of baseline data on the Australian freshwater crayfishes (Merrick 1993, 1995). This is somewhat surprising, given their bio-geographic status, and their potential as indicators of environmental health. Freshwater macro-invertebrates in general are considered indicators of environmental health (Faith and Norris 1989;

Norris and Norris 1995), but the reality of using some measure of change in this group requires further testing (Bunn 1995). The indicator species concept is one that has been developed in response to the impossibility of measuring the response of all species within an area to environmental perturbations and has gained wide acceptance (Anon. 1995). The establishment of useful bio-indicators requires demonstration that a change in the indicating organism's biology or ecology can be measured following environmental change.

E. hystricosus was selected as a possible indicator species to test the hypothesis that the quality of an animal's environment influences growth rate and/or abundance. This study was originally set up to examine the effects of logging on growth and population size of juvenile crayfish. Due to unforeseen and uncontrollable circumstances, open cut gold mining was re-instigated in the study area and its effects were also examined.

In the North Booloumba Creek catchment, logging occurred from 1986 to 1991; large scale open cut gold mining (from May 1987 to December 1988) left an environmentally unstable area; reclamation work has been sporadic up to the present. The Bundaroo catchment was selected as a relatively pristine area as a control against which to monitor changes on North Booloumba, as the catchment had no recorded history of logging or mining apart from gold prospecting and possibly some timber cutting for *Toona australis* (Red Cedar) at the turn of the century.

The objectives of this paper are to provide information on habitats and physico-chemical properties of the environment occupied by *E. hystricosus*; to document the growth rate of juvenile *E. hystricosus* in the wild and observed differences in growth rate in time and space; to investigate fluctuations in abundance of *E. hystricosus* juveniles in space and time; and to discuss impacts of habitat disturbance (logging, mining) on juvenile *E. hystricosus*.

MATERIALS AND METHODS

Study Area

The study area lies in the Conondale Ranges which begin north of the Brisbane Valley and include the Bellthorpe Range and Brooloo Ranges (Fig. 1). Central and northern parts of the Conondale Ranges are referred to as the Conondale and Kenilworth Units respectively; this study was primarily conducted in the Conondale Unit. The Conondale Unit drains south into Somerset Dam (Brisbane River catchment) via Kilcoy and Sandy Creeks, and west, north and east into the Mary River catchment (Fig. 1). The growth and abundance studies focused on the North Booloumba (26°42.5′S, 152°36′E) and Bundaroo Creek (26°41.5′S, 152^{O} 36.5′E) catchments (Fig. 2), at altitudes of 475–530 m.

Both creeks can be broadly described as permanent, montane, rocky watercourses with slow basal flows. For a detailed description of these waterways and associated riparian vegetation see Borsboom (1998).

During the study period both catchments were within state forest (SF 274) but were incorporated into Conondale National Park in June 1995 (Fig. 1).

Environmental data

Data were collected on the physico-chemical properties of the streams in both catchments and results of turbidity analyses as well as rainfall collection are presented in Figures 3 and 4; suspended solids (ppm) were used as a measure of turbidity. Positions of hydrology sampling stations are shown in Figure 2.

Rainfall records from the Kenilworth Forestry Station for the period of the study are provided in Figure 3.

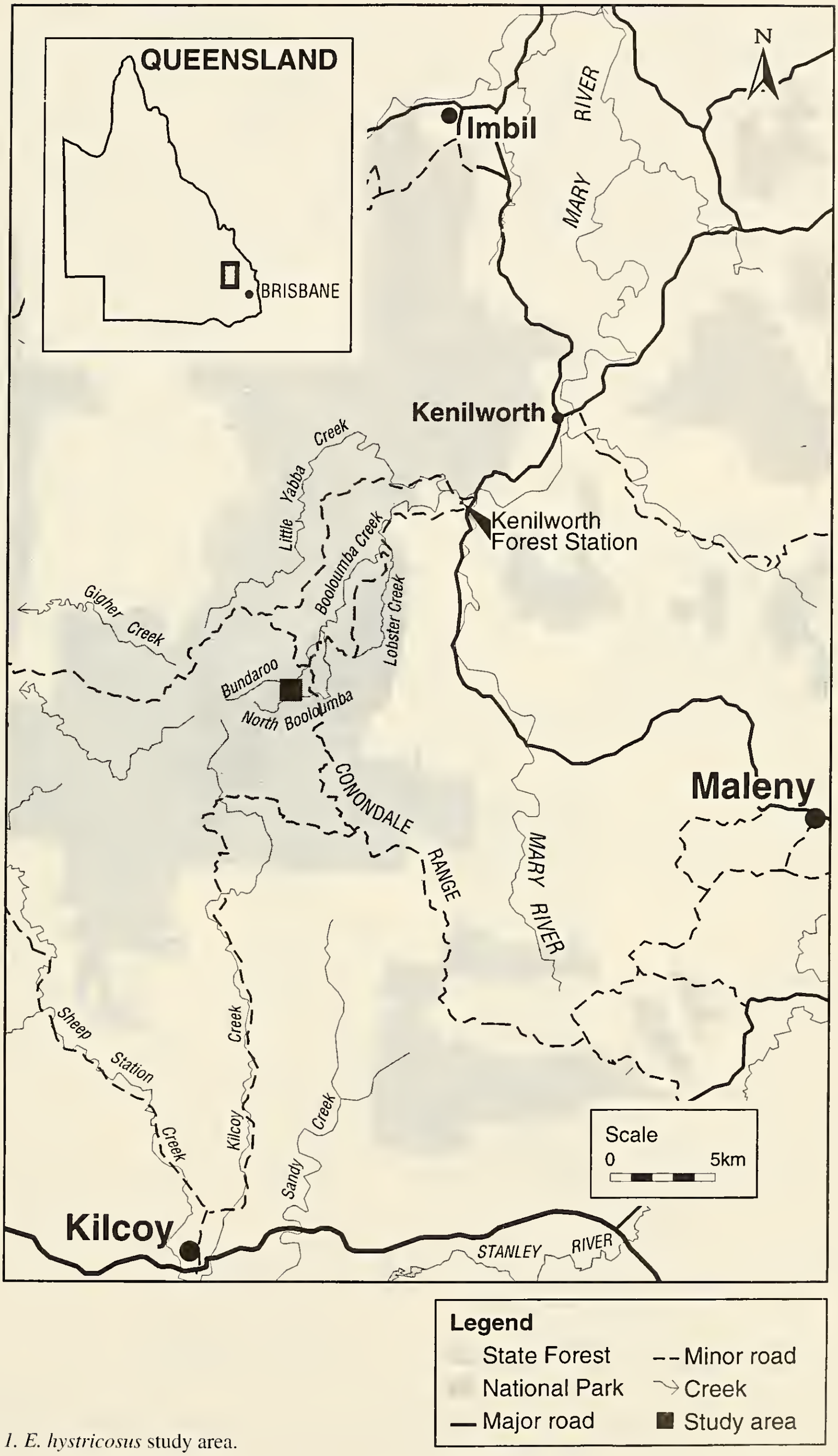


Figure 1. E. hystricosus study area.

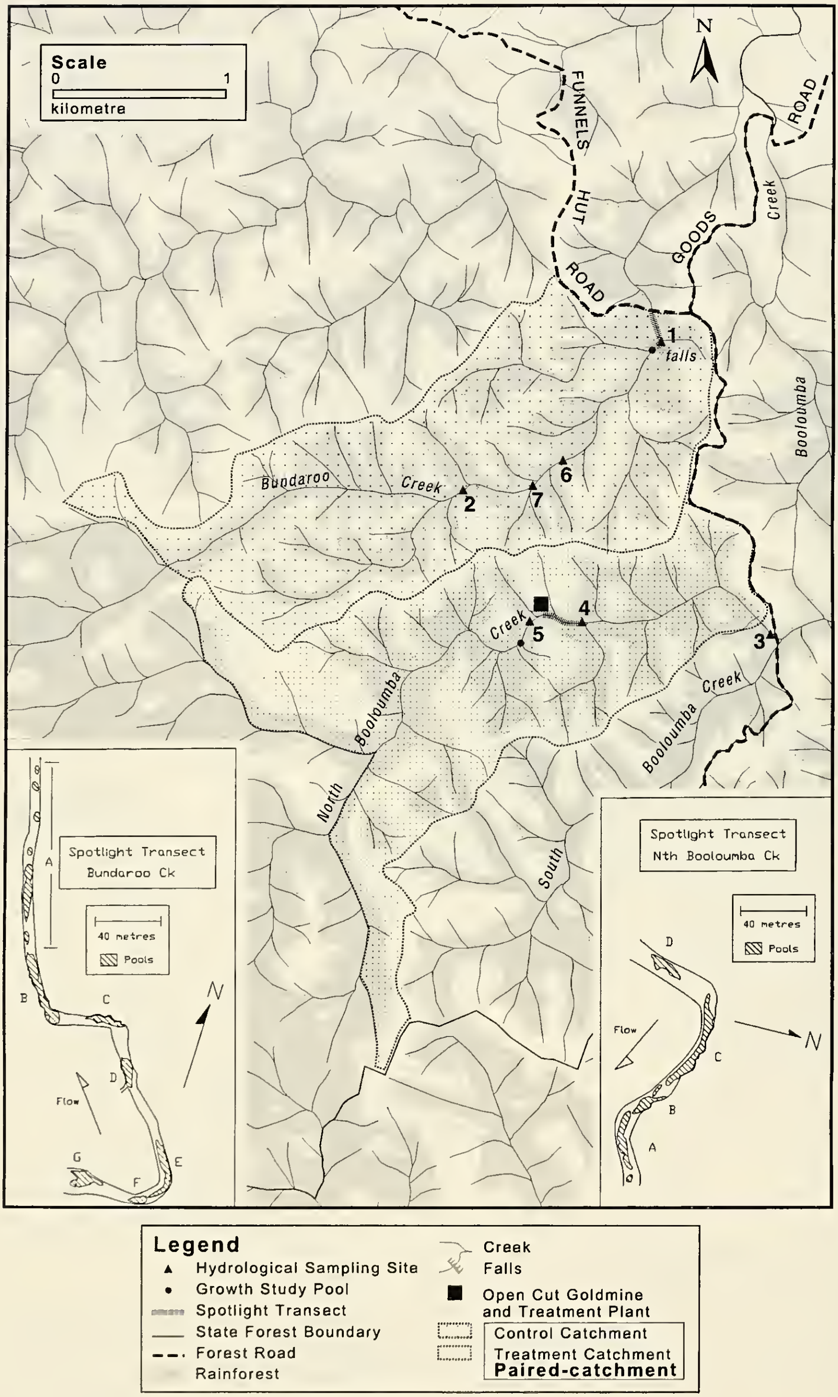


Figure 2. Features of the paired-catchment sites with details of abundance assessment transects (inserts). Note that the pools drawn within each of the streams (inserts) were connected by riffles.

Growth Measurements

Three locations were selected as collecting sites for growth investigations; these consisted of two pools separated by a riffle zone in North Booloumba Creek and a single pool in Bundaroo Creek (Fig. 2). Surveys indicated that *E. hystricosus* would be difficult to catch regularly without significant disturbance to their refuges under rocks or logs, so blocks of tubing were deployed in each pool to facilitate capture of crays; these artificial refuges were readily utilised by juvenile *E. hystricosus*. Each 'tube trap' consisted of two to four 300 mm lengths of black plastic tubing, 19–50 mm in diameter and set into concrete; tubes were open at both ends. Sixty blocks of tube traps were deployed in the paired catchment study pools at depths of 0.15–0.45 m. Sampling occurred in two periods: 1984–88 and 1991–94.

For a year following their release a target of 30 juveniles was sought for each monthly sample. Individuals were captured by carefully raising a tube trap horizontally off the creek bed and, while it was still underwater, tipping the contents into a hand held dip net. Occasionally crayfish were caught under a tube trap. Using Vernier calipers the ocular carapace lengths (OCL) of all specimens were measured (to nearest 0.1 mm) to assess the growth rate of seven cohorts from 1984 to 1994.

Abundance Measures

Spotlight survey transects were established on both Bundaroo and North Booloumba Creeks (Fig. 2). Numbers of juveniles seen along each transect were recorded monthly to provide estimates of relative abundances of each annual cohort. A census involved a single observer using a 55 W spotlight powered by a 12 V battery, walking the length of each fixed transect on two successive nights. Censuses were done in the first half of the night and only carried out when creeks were at basal flow. No stones or rocks were disturbed during a census, and numbers and estimated ages of individuals observed were recorded. Surveys were carried out between 1983 and 1987.

The total pool areas surveyed on each transect were 359 m^2 and 598 m^2 for Bundaroo and North Booloumba Creeks respectively. Depths of pools ranged from 0.09–1.05 m. Abundance estimates were obtained from the larger number of recorded crays located on each transect, over the two successive nights of spotlighting. Density estimates were calculated by dividing abundance numbers by the total pool area of the transect.

Analyses

The paired catchment study followed a "classic" BACI design (Bernstein and Zalinski 1983), where no replication of catchments occurred (Stewart-Oaten et al. 1986). Under these circumstances it is difficult to ascertain baseline data, as only relative comparisons can be made.

For control and treatment catchments the means of monthly OCL length samples for each first year cohort were divided into three groups (December–May, corresponding to the first summer and autumn as free-living individuals; June–September, the first winter as free-living individuals; and October–December, the post-winter period as free-living individuals prior to the release of a new cohort) and a linear regression line fitted to each grouping. These were tested for significance. Where significance occurred the slopes were tested for differences between catchments and between years. Mean OCL measurements recorded in May and December were also compared between catchments, for each first year cohort.

Correlation and t-tests (Sokal and Rolf 1981) were used to test for relationships between rainfall and turbidity and to test for differences in OCL measurements between catchments only in May of each year, following the first period of growth of the free-living juveniles. Comparisons were also carried out on OCL data for October–December between the two catchments where differences were apparent.

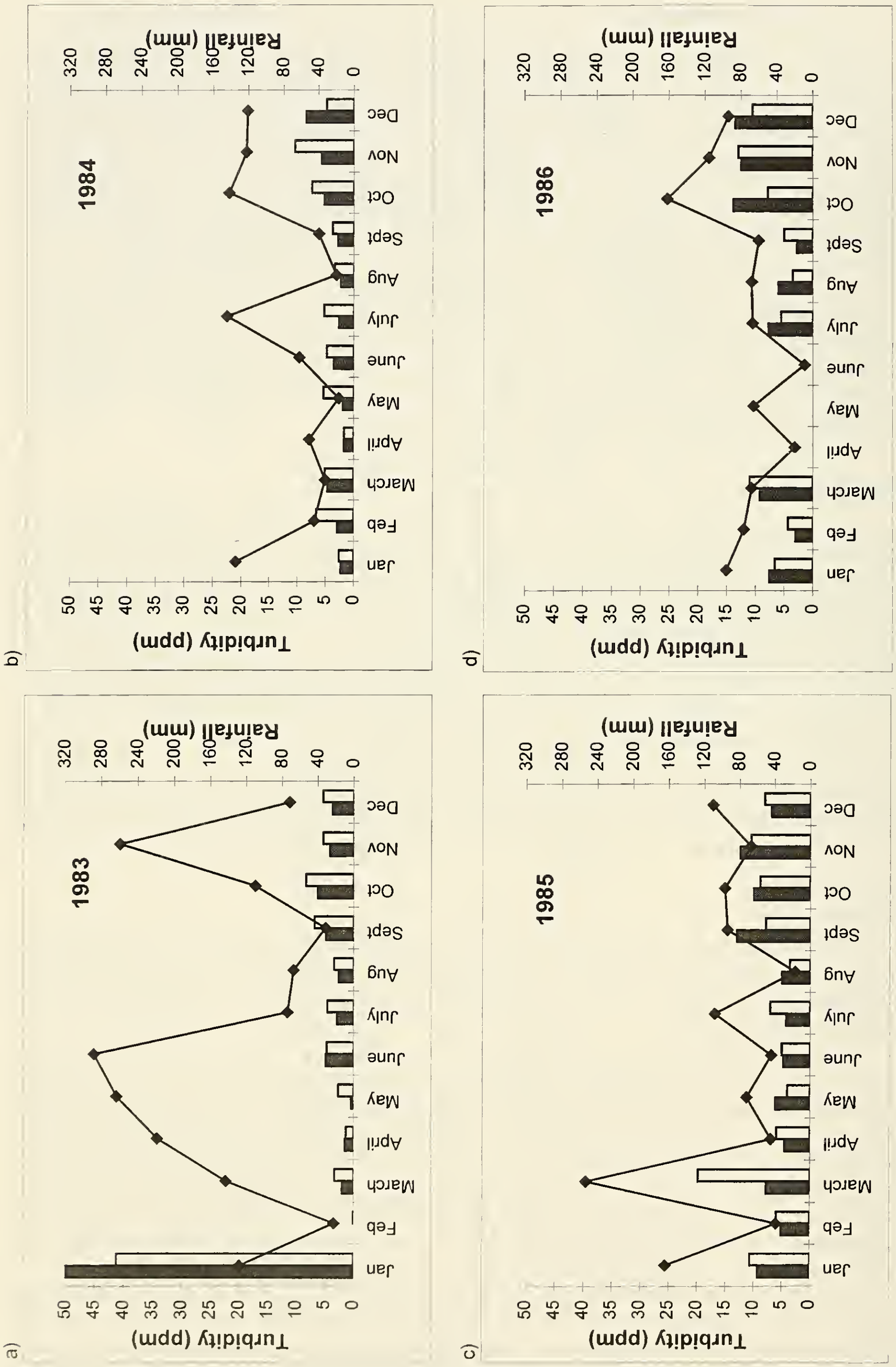


Figure 3. Summary of monthly turbidity data for both catchments, over a six year period, related to monthly rainfall records (from Kenilworth Forestry Station). Key to symbols on opposite page.

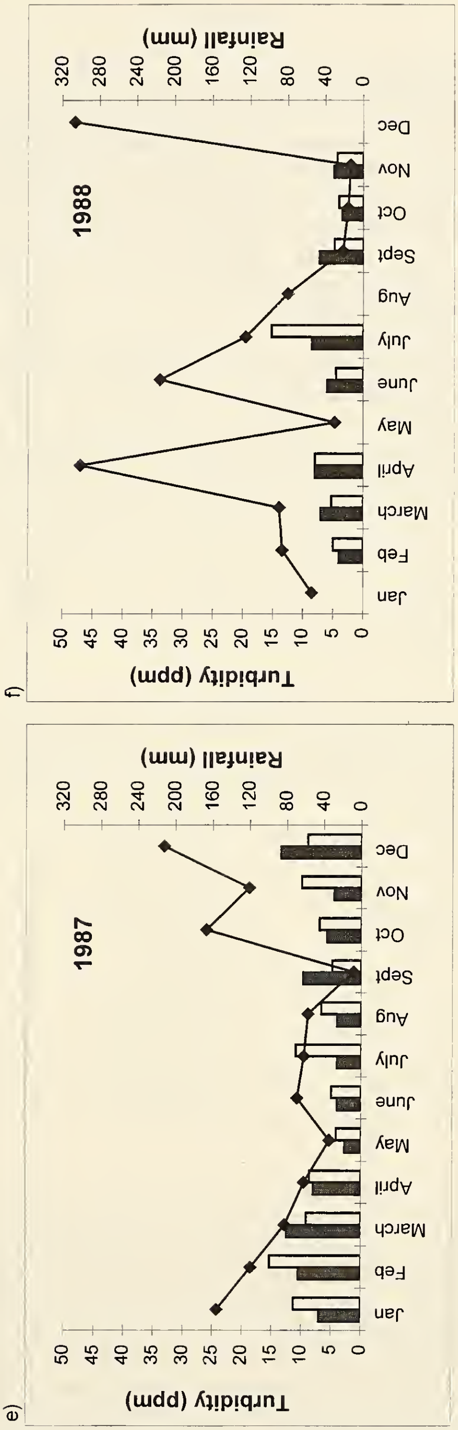


Figure 3 continued. Key to symbols: ■ = Booloumba Creek catchment; ☐ = Bundaroo Creek catchment; ✦ = total monthly rainfall.

RESULTS

Habitat, Environment and Water Quality

E. hystricosus was found to be essentially restricted to aquatic habitats. Adults construct burrows in the banks of streams and under large rocks with entrances either below or above the basal water line. Juveniles occurred mainly in shallow pools, taking refuge under rocks or logs and in rock crevices. Although juveniles did dig shallow excavations under rocks, burrow systems were not observed. Juvenile *E. hystricosus* have been recorded in deep pools as well as runs, glides and riffles; however, preliminary surveys have suggested that they are not evenly distributed among these stream environments (Borsboom and Kehl, unpublished data).

The physico-chemical properties of water flowing in the North Booloumba Creek are presented in Table 1. While there may be minor differences between catchments, this table seeks to highlight the range of conditions experienced by the crayfish living within the North Booloumba stream.

Turbidity data for each of the streams is presented in Figure 3. Natural fluctuations in turbidity were as large as any fluctuations that may have been induced by mining activities in general. No relationship was observed between turbidity and monthly rainfall data collected from Kenilworth Forestry Station (Pearson's Product-Moment Correlation Coefficient = 0.12, df = 64, p >0.05 for Booloumba; Pearson's Product-Moment Correlation Coefficient = 0.20, df = 64, p >0.05 for Bundaroo).

TABLE 1

Physico-chemical water parameters measured from locations above and below the mine site on North Booloumba Creek. Data supplied by Australian Laboratory Services Pty Ltd (to Department of Minerals and Energy, Queensland) from samples submitted and analysed 2 August 1996 to 22 May 1997.

Category of Parameter	Parameter	Values and Units
Physical	pH	6.5–7.4
	Conductivity	142–179 μS/cm
	Suspended Solids	1–3 mg/L
Major Cations	Ca	7–9 mg/L
	Mg	6–8 mg/L
	Na	11–17 mg/L
	K	<1–1 mg/L
Major Anions	SO4	4–12 mg/L
	Cl	21–27 mg/L

In general turbidity was normally higher in Booloumba Creek compared with Bundaroo Creek. Extraction of gold-bearing ore from a site on the Bundaroo Creek catchment in 1987 affected sediment loads in the creek and at one hydrological station turbidity was higher than upstream of the operation. However, compared with turbidity in North Booloumba Creek (Fig. 4), the difference was not statistically significant (t = –1.17, df = 59, p = 0.25). The open cut gold mine and gold extraction plant on North Booloumba Creek was downstream of the growth survey pool and upstream of the count transect. No significant turbidity effects were recorded at two of the three hydrological stations positioned within the North Booloumba catchment downstream of the mining area (Fig. 4) during or after the period of mining activity in 1987 and 1988.

Growth

Growth of each *E. hystricosus* year cohort in both control and treatment catchments, expressed as mean OCL of monthly samples, is shown in Figure 5. The smallest individuals measured occurred within the 4–6 mm class, while the largest (following a year of growth) fitted within the 20–22 mm size class.

Regressions for the December to May period showed all slope coefficients were statistically significant (Table 2). One of the June to September slope coefficients was statistically significant (North Booloumba — 1992–93) and one slope coefficient was statistically significant in the October to December period (North Booloumba — 1987—88). While the results suggest that the most significant period for growth was during the first summer-autumn following release, some growth may occur during winter and the following summer. The inconclusive results for the June–September and October–December periods may have been an artefact of the periods chosen; for example, if a September–December period were chosen (instead of October–December) then a little less than half of the slope coefficients tested were significant (Bundaroo — 1984–85: slope = 0.96, $p = 0.04$; 1985–86: slope = 0.94, $p = 0.06$; 1991–92: slope = 1.00, $p = 0.01$; North Booloumba — 1985–86: slope = 0.97, $p = 0.03$; 1987–88: slope = 0.96, $p = 0.22$).

TABLE 2

Summary of linear regressions of mean monthly OCL data for three sub-annual intervals for 7 yearly cohorts of E. hystricosus in Bundaroo and North Booloumba catchments.

	Dec–May				Jun–Sep				Oct–Dec			
Cohort	Bundaroo		N. Booloumba		Bundaroo		N. Booloumba		Bundaroo		N. Booloumba	
	Slope*	P	Slope	P	Slope	P	Slope	P	Slope	P	Slope	P
84–85					0.78	0.22	0.79	0.21	0.9	0.21	0.46	0.7
85–86	0.99	0.0007	0.99	0.0003	0.92	0.08	0.89	0.11	0.91	0.27	0.93	0.24
86–87	0.99	0.0001	0.99	0.0006	–0.81	0.4	–0.84	0.37				
87–88	0.99	0.05	1.0	0.004	0.89	0.3	0.63	0.56	–0.17	0.89	0.99	0.05
91–92	0.98	0.02	0.99	0.01	0.63	0.35	0.20	0.79				
92–93	0.97	0.001	0.97	0.001	0.68	0.32	0.97	0.02				
93–94	0.99	0.0001	0.99	0.0001	0.67	0.53	–0.88	0.31				

* Regression expression is OCL = A + B (Month) where OCL = Ocular Carapace Length, A= intercept on Y-axis, B= slope coefficient and Month= month of measurement.

Regression lines fitted to means during the December to May period were compared between years and catchments in an analysis of covariance. There was no significant difference in slopes ($F = 0.54$, $df = 1,23$, $p > 0.05$).

A comparison (student's t-test) of mean OCLs in May between catchments for each first year cohort indicated that mean OCLs were significantly greater in Bundaroo compared to North Booloumba in 1987 ($t = 2.13$, $df = 64$, $p < 0.025$) and in 1994 ($t = 2.8$, $df = 69$, $p < 0.005$). Other differences in mean OCLs evident in Figure 4 (particularly October 1993, 1994; November 1985; and December 1987, 1988) were investigated for statistically significant differences. Significant differences were found between the catchments in October 1993 ($t = 4.5$, $df = 46$, $p < 0.05$) and October 1994 ($t = 2.5$, $df = 63$, $p < 0.05$).

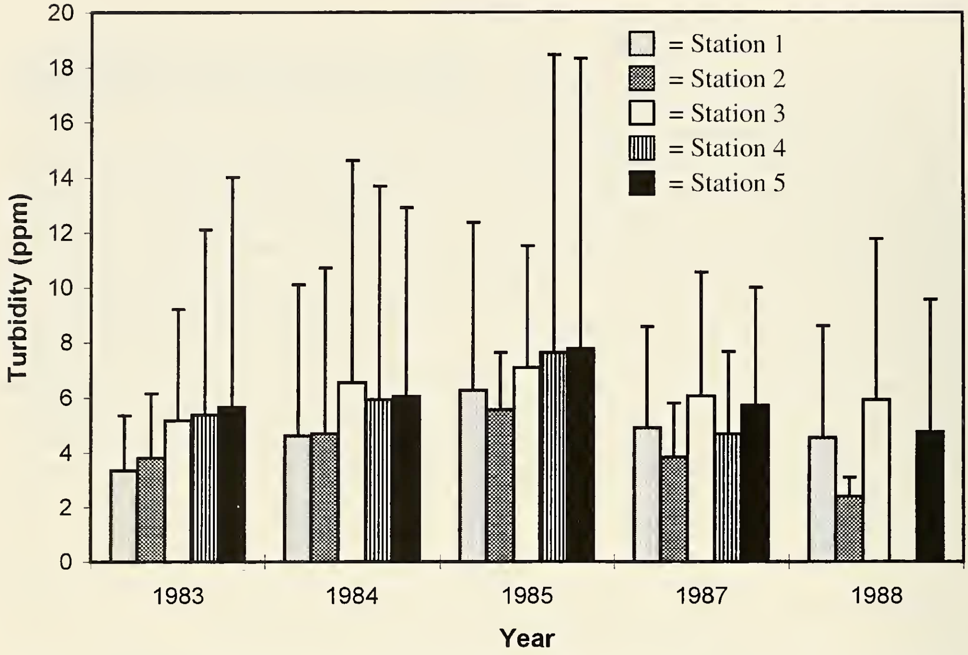


Figure 4. Mean turbidity data for each of five hydrology stations for six years in the Bundaroo and North Booloumba catchments.

Turbidity measures reflected no extraordinarily high occurrence of sediment loads in 1986 or 1987 (except at one station on Bundaroo, where the measure was not significantly different from that experienced in North Booloumba Creek); comparable measures were not available in 1994. It is difficult therefore to relate either of these significant results to turbidity. Rainfall measures also do not suggest any clear pattern as rainfall in 1986 and 1987 was fairly normal. Significant wet periods were recorded in 1983, 1988, 1989, in late 1991/92 and in 1996; but rainfall in 1993 (904 mm) and 1994 (870 mm) was well below the annual average of 1247 mm.

The only relationship apparent was that changes in growth rate (and the size of individual crays) in each of the catchments was associated with the commencement of mining (1987), although this activity has not been correlated with turbidity changes.

Abundance

Observed numbers and yearly trends in these numbers (for both transects) are shown in Figure 6. Monthly counts record the first appearance of each age class of juvenile crayfish and serve initially as an indication of the level of juvenile recruitment, while later in the year as an indication of juvenile survival. Observed numbers peak annually in the January–February period, then drop rapidly through winter, but recover partly in spring and early summer before commencing to drop again. Clearly these fluctuations are partially related to the detectability of crays, which is less in winter owing to their reduced activity.

The abundance estimates (Fig. 6) showed that juvenile *E. hystricosus* had similar annual fluctuations in numbers from year to year and across catchments. Only in 1984 were the numbers released in the two catchments considerably lower than in 1985 and 1986.

When standardised (by area of pools in each transect) to provide a density index, the numbers of crays per unit pool area were slightly lower to approximately the same in Bundaroo Creek compared to North Booloumba Creek. The commencement of logging in the North Booloumba catchment in May 1986 had no observable effect on early summer crayfish numbers.

DISCUSSION

The biology of the giant spiny crayfish is in many respects similar to that recorded for the freshwater crayfish *E. spinifer* for which there has been a considerable body of information recently documented (Merrick 1995, 1997; Turvey and Merrick 1997a, b, c, d, e). The timing of life history events may be slightly different. Spawning by *E. hystricosus* occurs in autumn (March–April) (Kehl, unpublished data) compared with early winter for *E. spinifer*, and eggs are carried by *E. hystricosus* across the winter period (egg incubation for *E. spinifer* is 110–140 days) (Merrick 1997). The eggs of *E. hystricosus* hatch from October to November (Kehl, unpublished data) compared with spring-early summer for *E. spinifer*. Juveniles are released late November to mid-December in *E. hystricosus* and early summer (Merrick 1997) for *E. spinifer* from the Sydney basin region.

This study has been a test case for using *E. hystricosus* as an "indicator" of stream integrity. The initial paired comparison of logged versus unlogged catchments was blurred by the gold mining in the control catchment in 1987. This activity was beyond the control of this study and caused an increase in turbidity at one hydrology station in that year. Relationships between physico-chemical parameters investigated and *E. hystricosus* are discussed further below.

Growth of freshwater crayfish is a function of both the inter-moult period and the moult increment. *E. spinifer* juveniles have been known to moult up to six times in their first year, although the average is 3 times per year (Turvey and Merrick 1997d). Like *E. spinifer*, *E. hystricosus* in their first year of independent life exhibit two periods of growth; these occur in the first summer and autumn of their free-living existence (December–May for *E. hystricosus*) and in the spring-summer period (October–December) following their first winter. Both *E. spinifer* and *E. hystricosus* show insignificant growth during the winter (Merrick 1997; Turvey and Merrick 1997d). This may be due to colder temperatures directly suppressing activity and therefore feeding behaviour or food availability itself.

Although the OCLs of crayfish found in Bundaroo Creek were typically larger in most months, significant differences were only recorded in May 1987 and May 1994. Growth rates were however, essentially the same; i.e. slopes did not differ significantly. There was no evidence to suggest that an earlier release occurred within Bundaroo Creek in 1987 and 1994. Growth itself however may be density dependent and it is important to recognize that good survival and highly fecund adults may produce an abundance which might suppress overall growth rates of individuals. Therefore, population size was monitored in parallel with growth rates.

Before discussing the relative abundances the following points need to be considered. Censuses were only carried out at times of basal flow, as raised levels increased turbidity and reduced detection rates; and counts were not performed during rainy periods, as rain on the surface also impaired visibility. Whether activity levels of juveniles during low flows in dry periods, on which estimates are based, are representative of movement at other times remains open to debate. Release numbers of juveniles and subsequent abundance estimates give relative indications of release time of juveniles, overall fecundity and survivorship. There was a clear similarity in the timing of release of juveniles and in the subsequent pattern of decline in numbers post-release observed in both catchments.

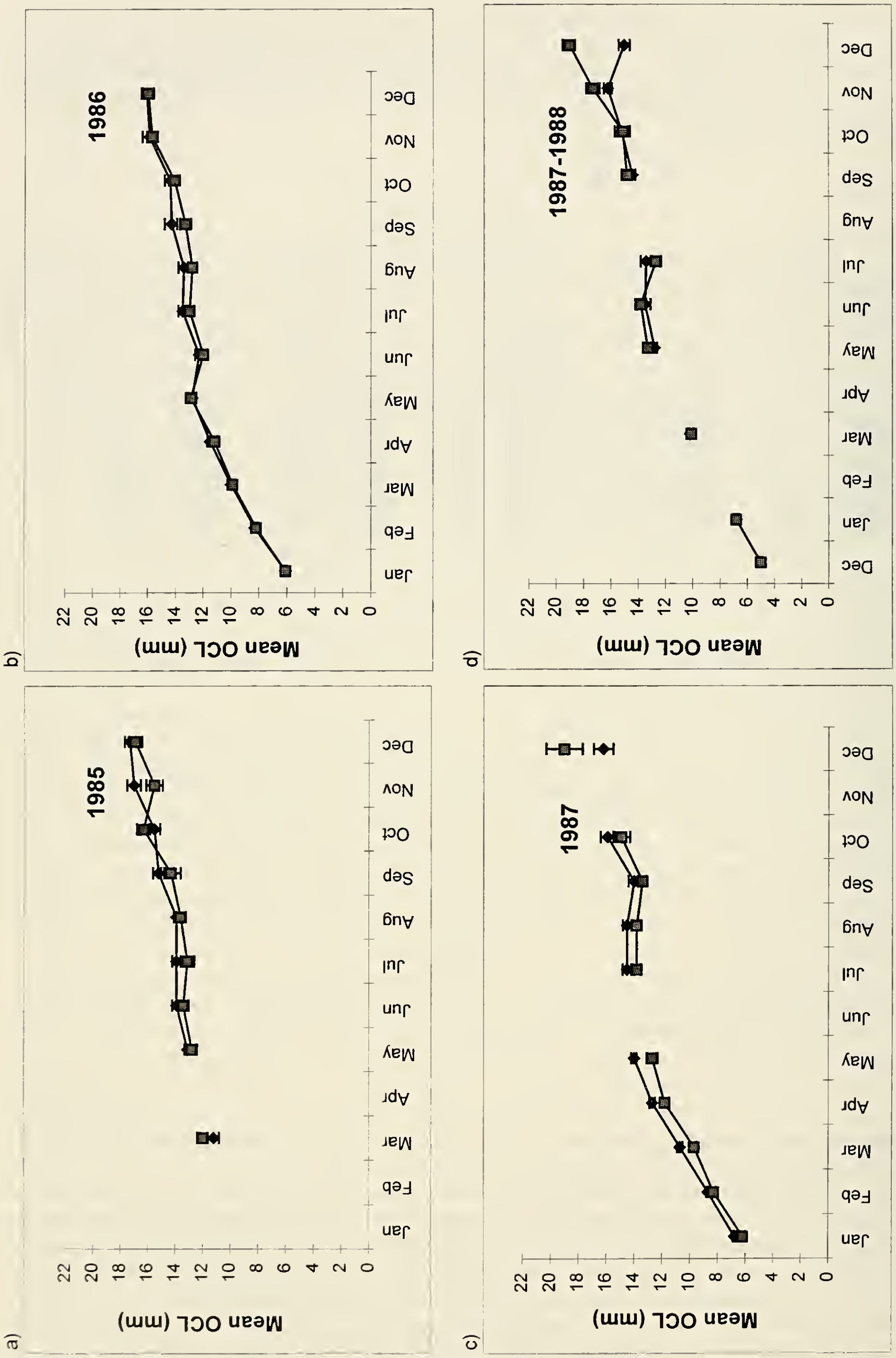
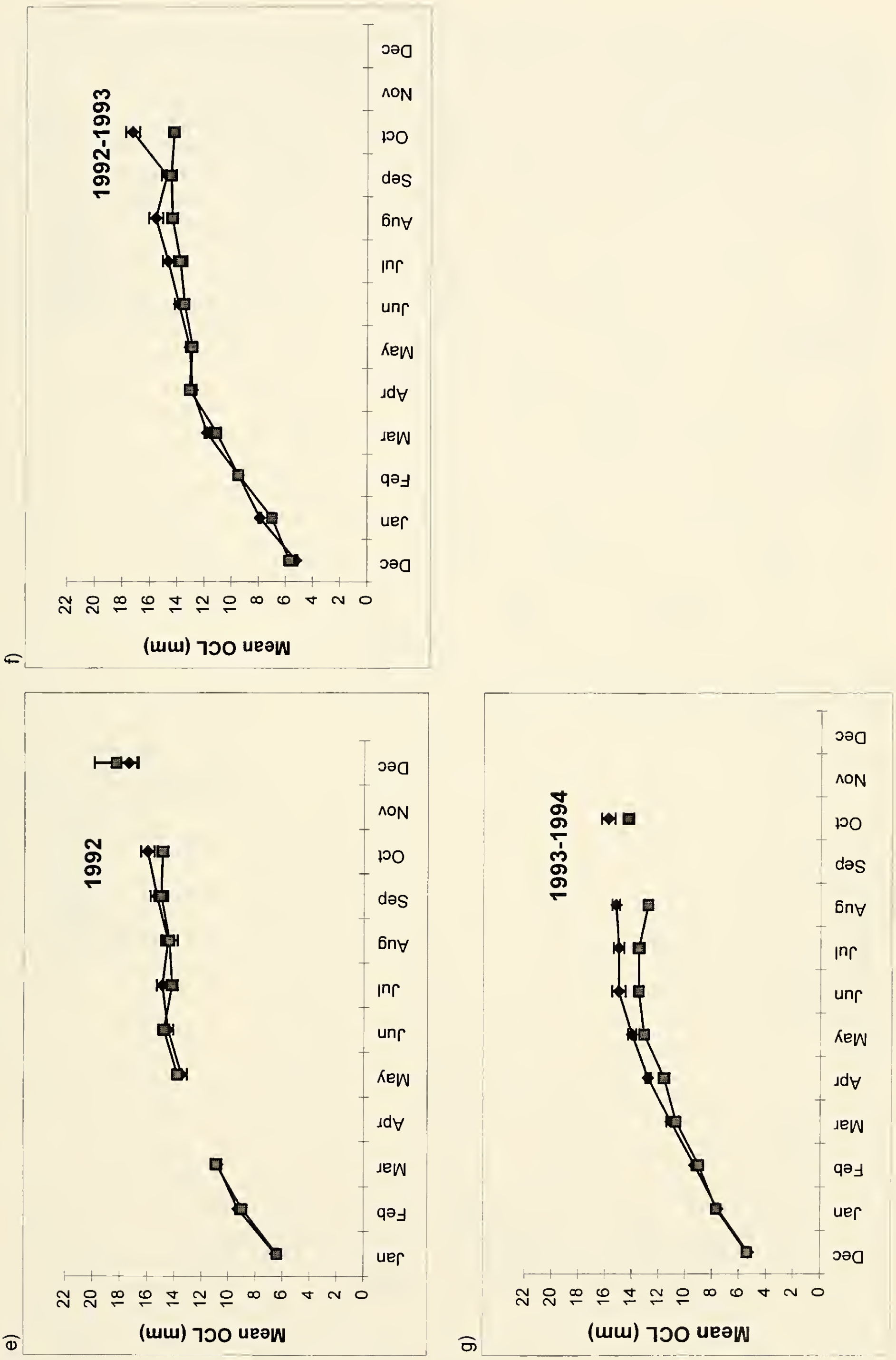


Figure 5. Summary of mean OCL data related to month for juvenile cohorts of *E. hystricosus* over a ten year period. Key to symbols: ■ = Booloumba Creek samples; ◆ = Bundaroo Creek samples



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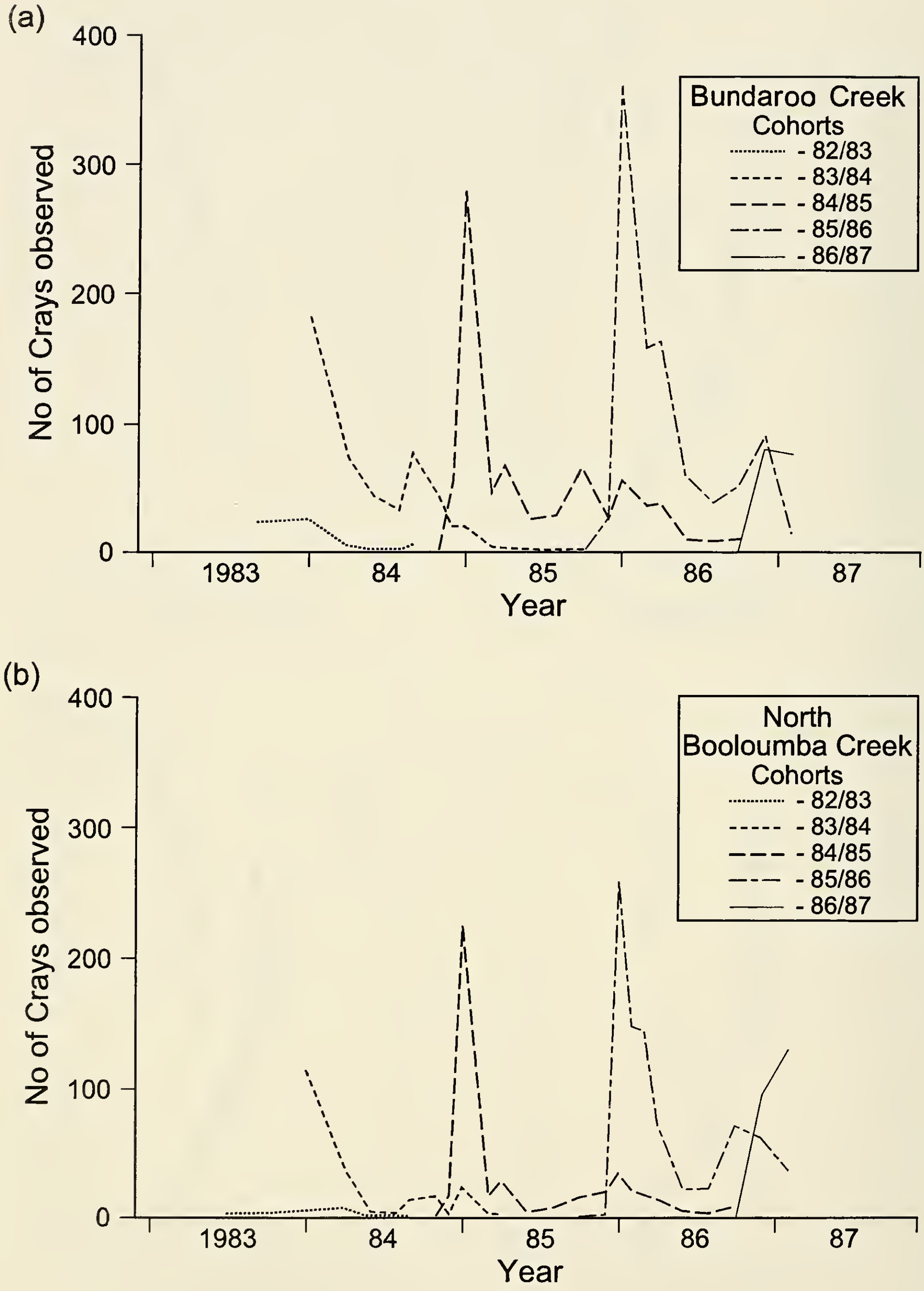

Figure 6. Summary of abundance estimates of five cohorts of juvenile *E. hystricosus* in the paired catchments; values are unstandardised for the length of survey transects. (a) Bundaroo Creek; (b) North Booloumba Creek.

Furthermore, the number of juveniles released in 1984–85 and 1985–86 were clearly much higher than the numbers released in 1983–84 and 1986–87; a pattern which was also consistent between catchments. While 1983 had been a wetter than average year, there is no suggestion that this was the primary cause of the differences noted. The effects of differing densities between years did not produce effects upon growth, although different densities between streams may in part explain why individuals were almost always a little larger in Bundaroo compared with North Booloumba. Clearly the observed differences cannot be easily explained on the basis of density-dependent effects.

Similarly, attempting to relate differences in growth to disparate physico-chemical parameters is also difficult. While turbidity measures within the streams did not differ appreciably between catchments, turbidity was typically higher in the North Booloumba catchment in all years (pre- and post-disturbance). Turbidity was also markedly affected in 1987 when gold-bearing ore was removed from a site on the Bundaroo catchment, with a significant difference occurring between turbidity measures above and below the site and significantly larger juveniles occurring in Bundaroo Creek in that season.

Growth data did not correlate well with turbidity data, probably because of the inability of the equipment available at the time to detect high run-off episodes associated with mining at least. The technology is now able to record such events. It is unlikely selective logging activities produced higher than normal stream turbidity levels during high run-off episodes; this is partly because most of the unlogged vegetation buffers along permanent and semi-permanent watercourses within the North Booloumba catchment were considerably wider than the 10 m wide buffers that were standard logging practice at the time.

Rainfall data did not correlate well with turbidity data as turbidity is greatly affected by episodic rainfall events within each catchment and may go undetected at the Kenilworth Forestry Station. Similarly rainfall could not be correlated with growth or abundance data, which serves further only to highlight the difficulties we experience in attempting to measure environmental and life history characteristics on the same time/space scales.

While this project provides background information about the habitat requirements, fluctuations in growth rates and abundance of *E. hystricosus* within the Conondale Unit of the Conondale Ranges, the patchiness of data collected over many years makes it difficult to make definitive causal connections between life history parameters (growth, abundance) and changes in the environment due to anthropogenic effects (forestry, mining).

In terms of assessing whether *E. hystricosus* has been useful as a monitoring tool for detecting adverse environmental change, we can only say that it is unclear even still. It is apparent however, that *E. hystricosus* has the same characteristics (i.e. it is easy to mark individuals; it shows sedentary behaviour; it has limited physiological tolerances; and it has a long life span (Borsboom and Kehl, unpublished data)) that make *E. spinifer* an ideal organism for bio-monitoring (Merrick 1997). However, suffice it to say that any monitoring program requires long-term commitment in all its respects and it is critically important that the scale at which measurements are taken should be considered carefully so that no fine scale relationships are overlooked in the final synthesis.

We recommend further studies and monitoring of *E. hystricosus* at other sites within the range of this species, to further assess its ecological requirements and any potentially adverse impacts from anthropogenic influences (Merrick 1995). Prior to formulating specific conservation strategies for *E. hystricosus* the recent management findings on other large *Euastacus* species of recreational importance should be considered (Barker 1990; Honan and Mitchell 1995; Merrick 1997). Populations of *E. hystricosus* are relatively well conserved within state forests and national parks in Queensland. Illegal harvesting is a possible threat, however, within the Conondale National Park a number of access roads to water courses with *E. hystricosus* have recently been closed to the public. Monitoring of the species and control of illegal harvesting will do much to ensure the cray's security on state forest.

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